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SPECKLE INTERFEROMETRY AT THE U.S. NAVAL OBSERVATORY. XX

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ABSTRACT

Results are presented of 4222 intensified CCD observations of double stars, made with the 26 inch refractor of the U.S. Naval Observatory in 2013 and 2014. These observations are averaged into 2335 mean relative positions and range in separation from 0″.53 to 83″.90, with a median separation of 11″.42. This is the 20th in this series of papers and covers the period 2013 January 4 through 2014 December 18. Also presented are 13 pairs which are measured for the first time, 12 pairs which appear to be lost, linear elements for 17 pairs, and orbital elements for five additional pairs. Finally, we investigated apparent systematic residuals to earlier measures in this series, and modify scale factors for closer pairs observed between 1990 and the present.

Key words: binaries: general – binaries: visual

Supporting material: machine-readable and VO table

1. INTRODUCTION

This is the 20th in a series of papers from the U.S. Naval Observatory's speckle interferometry program, presenting results of observations obtained at the USNO 26 inch telescope in Washington, DC (see, most recently, Mason et al. 2013). Nearly 30,000 mean positions have now resulted from this program since its inception by Charles Worley, Geoff Douglass, and colleagues in the early 1990s (see Douglass et al. 1997).

From 2013 January 4 through 2014 December 18, the 26 inch telescope was used on 135 of 451 scheduled nights. Most of the remaining nights were lost due to weather conditions, as well as equipment upgrades, mechanical issues, and a lack of observing personnel. All observations were obtained with one of two "secondary" cameras. The first camera, described in Mason et al. (2007) and used through 2014.195, utilizes a set of microscope objectives, providing a field of view up to ∼60″. The second camera, used after 2014.195, utilizes simple lenses, and provides a field of view up to ∼80″.

Most of the systems observed with this camera have separations well beyond the regime in which there is any expectation of isoplanicity, so we classify the observing technique for all of these measures as just "CCD astrometry," rather than speckle interferometry. Despite this classification, there is an expectation that the resulting measurements have smaller errors than classical long-focus CCD astrometry. Each measurement is the result of many hundreds of correlations per frame, and up to several thousand frames per observation. This ensemble of observations is processed and measured using the conventional directed vector autocorrelation techniques used by the CHARA and USNO speckle teams for over 20 years.

During this two-year period, a total of 4609 observations were obtained, yielding 4683 resolutions (this somewhat non-intuitive >100% "success rate" is the result of our frequent observations of multiple star systems within a single CCD field). After removing marginal observations, calibration data, tests, and "questionable measures" a total of 4208 measurements remained. It should be noted that "questionable measures" are not ones of inferior quality, but rather those that show significant differences from the most recently published measures of these pairs. (These differences are usually not surprising, as the most recent measures were often made many decades ago.) Before any of these measures are published they will be confirmed in a new observing season to account for any other possible errors, such as pointing or other identification problems. A tabulated list of these pairs is retained and forms a "high priority observing list" for subsequent observing seasons.

The 4208 measures obtained in 2013–2014 were grouped into 2324 mean relative positions, including 11 confirmations of double stars having only one previous observation. An additional 11 means were included for pairs observed between 2007 and 2012; these were earlier "questionable measures" subsequently confirmed by more recent observations. Motion for most of the observed pairs is sufficiently slow that our mean measures are usually averages over an entire observing season. However, multiple means are generated whenever possible for any pairs going through rapid motion during a season.

Observing list construction and calibration procedures remain the same as those described for the "secondary" camera in Mason et al. (2007). This method also allowed us to use double stars to evaluate the observing system accuracy and precision by observation of pairs with well-characterized orbital or linear solutions. Evaluation of the ensemble of tabulated O−C values in Table 2 allows the error to be grossly characterized as ±1°.0 in position angle and ±1% × ρ in separation.

2. RESULTS

2.1. New Pairs

Table 1 presents coordinate and magnitude information from CDS[1] for 13 pairs which are presented here for the first time. All were observed as either additional components to known systems or pairs in the same field of view as objects on our observing lists. Column one gives the J2000.0 coordinates of the primary of the pair. Column two lists the WDS designation (based on the epoch-2000 coordinates of its system primary), Column 3 the discoverer designation (where WSI = Washington Stellar Interferometer) and component

[1] Magnitude information is from one of the catalogs queried in the Aladin sky atlas, operated at CDS, Strasbourg, France.

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14. ABSTRACT
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Table 1
New Pairs

Coordinates α, δ (2000)	WDS Designation	Discoverer Designation	Magnitudes Primary	Magnitudes Secondary	Note
06 35 45.36 +04 56 11.9	06358+0456	WSI 156 AC	12.03	13.2	1
06 35 45.36 +04 56 11.9	…	WSI 156 AD	12.03	13.1	1
07 49 17.34 +04 24 45.6	07493+0425	WSI 157 AC	11.9	12.2	…
07 49 17.82 +04 24 39.0	…	WSI 157 BC	12.2	12.2	…
09 41 00.92 +05 05 08.1	09410+0505	WSI 161 AC	11.39	12.34	…
13 57 13.89 +02 25 17.5	13572+0225	WSI 158 AB	12.9	13.9	1, 2
17 14 44.25 +23 56 22.1	17148+2356	WSI 159 AC	11.81	13.0	…
19 03 42.48 −00 04 13.5	19037−0004	WSI 160 AC	11.6	12.8	1, 2
19 03 42.33 −00 04 03.2	…	WSI 160 BC	12.6	12.8	1, 2
20 10 09.67 +36 17 09.2	20101+3617	WSI 152 AC	11.4	14.1	1
22 29 00.40 +11 59 58.3	22290+1200	WSI 153 Ba,Bb	12.4	13.9	1
23 27 45.75 +30 05 10.4	23277+3005	WSI 154 AC	10.47	10.8	1
23 34 24.27 +03 31 15.4	23344+0331	WSI 155	12.0	13.3	3

Notes.
(1) Physicality status unknown, but closer than the published pair.
(2) Magnitudes are red, not visual.
(3) Measure originally assigned to WDS 23340+0334 = BAL2581 in WSI2002, but does not match that pair closely enough. The measure has been reassigned to this new pair.

Table 2
Relative Astrometry of Double Stars

WDS Designation	Discoverer Designation	Epoch 2000.+	θ (deg)	ρ (″)	n	O−C (deg)	O−C (″)	Reference	Note
00012+1357	WNO 12	14.862	203.5	11.57	2	…	…	…	
00013+5604	HJ 1925	13.885	341.7	19.17	2	…	…	…	
00037+1252	HJ 3235	14.862	87.2	22.78	2	…	…	…	
00038−1317	XMI 1	14.862	271.1	29.15	1	−0.1	−0.12	USN2013a	
00048−0952	HU 100	14.862	343.5	4.05	1	…	…	…	
00057+4549	STT 547 AB	13.874	186.8	5.98	2	−1.3	0.06	Pop1996b	
						−0.8	−0.04	Kiy2001	
00057+4549	STT 547 AE	13.874	345.8	57.53	1	0.1	0.36	Hrt2011c	
00057+4549	STT 547 BE	13.874	347.7	63.14	1	…	…	…	
00062+1900	DAM 275	13.947	322.1	9.51	1	…	…	…	

Notes.
C : Confirming Observation.
G : First seen in the eyepiece of the 200″ in Grf2012b (Section 4.49). The new measure is closer than that rough estimate, although the period is still probably well over 100y.
I : The measure was assigned to this pair as it was the only likely double in the field, but the identification is uncertain.
N : New pair. See Table 1.
O : The older measure was significantly different from historical measure(s). The large change in position has been confirmed by other recent observations, either by us or in other publications.
R : "Rapid-moving" pairs (defined as pairs having orbital periods under 100 years).
V : This is the vector addition of measures of other pairs in this multiple system.
= 53–121 : Not measured in # years.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms.)

pair. Columns 4 and 5 give the visual magnitudes of the primary and secondary (except as noted), and Column 6 notes the circumstance of the discovery. Mean double star positions (T, θ, and ρ) of these systems are given in Table 2.

2.2. Measures of Known Pairs

Table 2 presents 2335 mean relative position for 2204 different pairs. The first two columns identify each pair by providing its WDS designation and discovery designation. Columns 3 through 5 give the epoch of observation (expressed as a fractional Besselian year), the position angle (in degrees), and the separation (in seconds of arc). Note that the position angle, measured from north through east, has not been corrected for precession, and is thus based on the equinox for the epoch of observation. Objects whose measures are of lower quality are indicated by colons following the position angle and separation. These lower-quality observations may be due to one or more of several factors: close separation, large magnitude difference, faint primary and/or secondary, large zenith distance, and poor seeing or transparency. Errors for these measures are perhaps two to three times those of typical measures, so they are included only if they confirm a previously unconfirmed pair (i.e., a pair with only a single

Table 3
New Orbital Elements

WDS Designation	Discoverer Designation	P (year)	a ($''$)	i (deg)	Ω (deg)	T_0 (year)	e	ω (deg)	Gr
05005+0506	STT 93	743.8	1.829	97.9	60.3	1897.2	0.431	49.2	4
		±114.2	±0.172	±2.0	±1.3	±14.3	±0.029	±18.5	
11486+1417	BU 603	129.74	0.734	140.4	228.4	1943.84	0.804	77.0	3
		±2.02	±0.046	±6.2	±13.2	±3.00	±0.024	±9.2	
13198+4747	HU 644 AB	48.776	1.5198	94.43	91.15	1968.459	0.2148	72.65	2
		±0.090	±0.005	±0.20	±0.17	±0.117	±0.0070	±0.71	
14203+4830	STF 1834	413.4	1.009	76.1	287.0	1902.6	0.903	355.8	3
		±46.0	±0.029	±4.5	±1.6	±2.1	±0.042	±6.7	
14489+0557	STF 1883	226.28	0.8115	107.26	99.61	1965.35	0.6261	42.24	2
		±1.84	±0.0036	±0.33	±0.25	±0.22	±0.0037	±0.62	

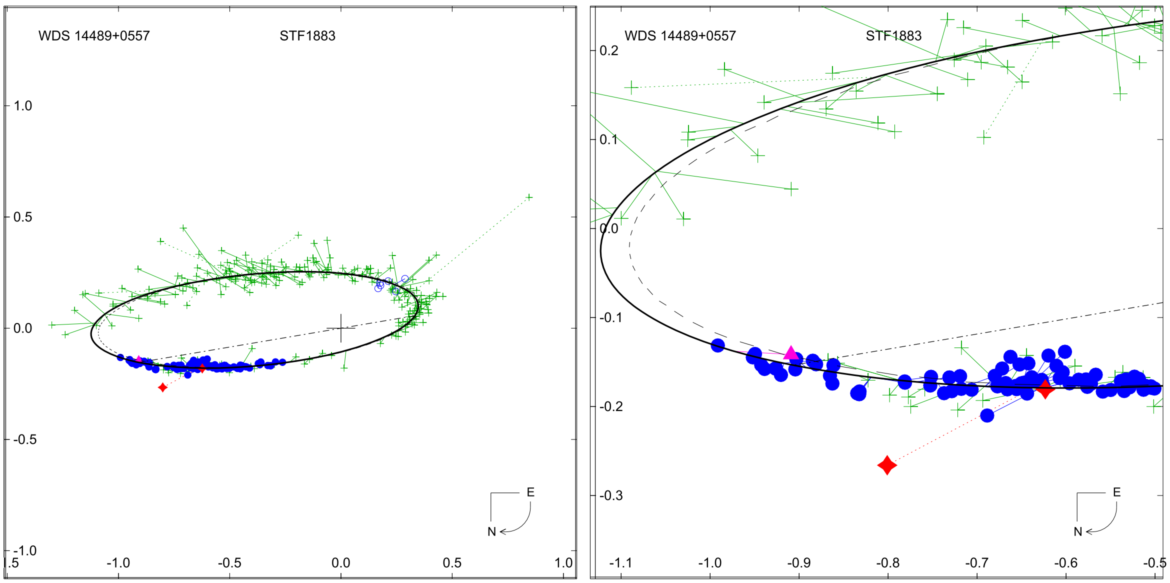

Figure 1. Left panel illustrates the new orbital solution for WDS 14489+0557 = STF 1883, plotted together with all published data in the WDS database as well as the new data from Table 2. Micrometric observations are indicated by plus signs, interferometric measures by filled circles, CCD measures by filled triangles, eyepiece interferometry measures by open circles, and Hipparcos/Tycho measures by filled diamonds. "O–C" lines connect each measure to its predicted position along the new orbit (shown as a thick solid ellipse). Dashed "O–C" lines indicate measures given zero weight in the final solution. The dotted–dashed line indicates the line of nodes, and a curved arrow in the lower right corner of each figure indicates the direction of orbital motion. Scales are in arcseconds. The previous published orbit (USN2000c) is shown as a dashed ellipse. The right panel shows a magnified portion of the ellipse, and illustrates the manner in which the new measures were beginning to "run off" from the earlier solution.

published measure), or if the number of years since the last measured position is significantly large. The sixth column indicates the number of independent measurements (i.e., observations obtained on different nights) contained in the mean. Columns 7 and 8 give residuals in θ and ρ to values predicted by the published orbit or linear solution referenced in Column 9.[2] Finally, Column 10 flags any notes.

The most common note indicators are either "C," indicating a confirming observation, "N," indicating a new pair, or "O," indicating a pair which has seen considerable change since earlier publications. Twelve systems are confirmed here.

Since priority is given to both unconfirmed systems and to systems not observed recently, the time since last observation can be surprisingly large; six systems had not been observed in 50 years or more, four of these for at least a century. The maximum such time span was 121 years for SEI 852, last observed by Scheiner (1908) in 1893. A number in the notes column indicates the length of time in years since these "long-neglected" systems were last measured.

2.2.1. New Orbital Elements

New orbits are presented in Table 3. In this table, the pairs are identified by their WDS and discoverer designations. The orbital elements follow, giving the period (P in years), the semimajor axis (a'' in arcseconds), the inclination (i) and longitude of the node (Ω), both in degrees, the epoch of the most recent periastron passage (T_0 in Besselian years), the eccentricity (e), and the longitude of periastron (ω in degrees). Following this is an evaluation of the orbit (see Hartkopf et al. 2001 for a description of the orbit grading criteria). Formal errors are listed just below each element. An example of a new orbit solution is given in Figure 1; notes on the new solutions follow:

WDS 05005+0506 (= STT 93): Although named for Otto Struve, this solar-type pair was first resolved by Mädler in 1846 (Mädler 1856). After nearly 170 years and 100 observations,

[2] Reference codes in Table 2 and elsewhere are those used in all USNO double star catalogs; all are defined in the list of references.

Table 4
New Rectilinear Elements

WDS Designation	Discoverer Designation	x_0 (″)	a_x (″ yr^{-1})	y_0 (″)	a_y (″ yr^{-1})	T_0 (year)	ρ_0 (″)	θ_0 (deg)
02070+4512	WOR 1 AB	−1.592764 ±0.105375	−0.255066 ±0.002726	0.895355 ±0.070326	−0.453742 ±0.001759	1952.131 ±0.042	1.827 ±0.098	240.66 ±2.51
02070+4512	BKO 12 AC	−8.773132 ±0.069608	−0.222690 ±0.013988	4.500978 ±0.095153	−0.434059 ±0.016039	2004.061 ±0.148	9.860 ±0.076	242.84 ±0.53
02070+4512	LMP 27 AD	−23.614973 ±0.223963	−0.251395 ±0.003155	13.487535 ±0.420192	−0.440162 ±0.005955	1935.442 ±0.258	27.195 ±0.285	240.27 ±0.80
02113+4407	ES 2590	−3.843749 ±0.355628	0.307261 ±0.005836	8.444369 ±0.839884	0.139860 ±0.013869	1904.818 ±0.131	9.278 ±0.778	204.47 ±2.93
03480+6840	WNO 16 BD	−11.300430 ±0.938266	−0.096531 ±0.020464	−3.447614 ±0.597567	0.316403 ±0.012813	2047.473 ±0.352	11.815 ±0.914	286.97 ±3.07
03502+3449	ES 277 AB	2.914210 ±2.192220	−0.046813 ±0.008065	−1.666779 ±1.696229	−0.081847 ±0.006240	2231.414 ±0.169	3.357 ±2.081	60.23 ±31.25
03546+3519	HJ 669 AC	−25.997791 ±0.344269	−0.070803 ±0.002823	36.870064 ±0.573393	−0.049925 ±0.004704	2073.573 ±0.175	45.114 ±0.509	215.19 ±0.55
05066+0152	HJ 2250	10.446773 ±0.447010	0.002959 ±0.004040	0.763383 ±1.271727	−0.040493 ±0.011494	1812.507 ±0.073	10.475 ±0.455	94.18 ±6.94
05588+7134	STF 793	−1.453096 ±0.078263	0.076154 ±0.000782	−2.009910 ±0.087539	−0.055057 ±0.000875	2041.270 ±0.008	2.480 ±0.084	324.13 ±1.88
06062+0629	STF 841	−6.450593 ±0.479205	0.053570 ±0.003183	−11.008491 ±0.172866	−0.031390 ±0.001148	1809.394 ±0.047	12.759 ±0.284	329.63 ±1.90
06345+0420	BAL 2672	5.538126 ±0.618597	−0.022212 ±0.005436	−3.198691 ±0.509984	−0.038458 ±0.004482	1848.973 ±0.044	6.396 ±0.593	59.99 ±4.83
13443+6841	HJ 2685	−8.616816 ±0.395527	−0.040960 ±0.001763	10.930032 ±0.602793	−0.032291 ±0.002687	1699.493 ±0.049	13.918 ±0.533	218.25 ±2.00
14098+0822	A 1098	−3.691854 ±0.034333	0.000614 ±0.000695	−0.069062 ±0.028707	−0.032803 ±0.000581	1995.302 ±0.003	3.692 ±0.034	271.07 ±0.45
16264+5047	BEM 9021	10.546416 ±0.236771	0.040081 ±0.004512	−14.274570 ±0.098510	0.029613 ±0.001877	1914.118 ±0.050	17.748 ±0.161	36.46 ±0.64
17211+0127	STF 2150 AB	2.170707 ±0.142783	−0.032299 ±0.000810	7.159655 ±0.172788	0.009793 ±0.000980	1749.992 ±0.008	7.481 ±0.170	163.13 ±1.11
17344+2520	HJ 1300 AB	−11.886831 ±0.158077	0.010494 ±0.001853	2.501439 ±0.091634	0.049869 ±0.001074	2035.188 ±0.022	12.147 ±0.156	258.12 ±0.45
22016+4921	ES 831 AD	−3.645931 ±1.361910	−0.036926 ±0.004276	−4.618294 ±4.096705	0.029152 ±0.012862	2276.321 ±0.089	5.884 ±3.324	321.71 ±26.82

the orbit is still obviously very preliminary, as the pair has yet to complete even 1/4 of a revolution.

WDS 11486+1417 (= BU 603): The primary is an A8III; the magnitude difference (∼2.5 mags) suggests the companion is perhaps a mid-G dwarf. The pair has completed just over one full revolution since its discovery in 1878, but half the orbit is essentially unobserved, due to the pair's high eccentricity. Indeed, the pair was unresolved between 1935 and 1956, as it moved through some 250° of its orbit.

WDS 13198+4747 (= HU 644 AB): Over half of the orbit for this 49-year pair is now covered by high-resolution data—enough that the period for this solution was determined from all 112 years' worth of micrometry, speckle, adaptive optics (AO), and CCD data, then the remaining elements were based solely on speckle and AO measurements. The primary is listed as K0; based on the magnitude difference the secondary is probably about K3. The A component was resolved by speckle into a close (0.″1) Aa,Ab pair (Hartkopf et al. 1994); Ab is perhaps a mid-K star.

WDS 14203+4830 (= STF 1834): This high-eccentricity pair has completed less than half a revolution since its discovery in 1829 (Struve 1837). Recent measures have

Table 5
Ephemerides for New Orbit and Linear Solutions

WDS Designation	Discoverer Designation	2014.0 θ (°)	2014.0 ρ (″)	2016.0 θ (°)	2016.0 ρ (″)	2018.0 θ (°)	2018.0 ρ (″)	2020.0 θ (°)	2020.0 ρ (″)	2022.0 θ (°)	2022.0 ρ (″)
02070+4512	WOR 1 AB	327.4	32.256	327.5	33.295	327.6	34.335	327.7	35.374	327.8	36.414
02070+4512	BKO 12 AC	269.0	10.988	273.4	11.452	277.4	11.978	281.1	12.558	284.4	13.184
02070+4512	LMP 27 AD	295.9	48.221	296.6	49.062	297.2	49.909	297.9	50.762	298.5	51.621
02113+4407	ES 2590	128.6	38.009	128.4	38.664	128.1	39.320	127.9	39.976	127.7	40.633
03480+6840	WNO 16 BD	330.1	16.192	328.4	15.747	326.5	15.318	324.5	14.906	322.5	14.512
03502+3449	ES 277 AB	140.9	20.773	140.8	20.587	140.8	20.401	140.7	20.215	140.6	20.029
03546+3519	HJ 669 AC	208.7	45.408	208.9	45.389	209.1	45.370	209.3	45.352	209.5	45.335
05005+0506	STT 93	243.8	1.563	243.6	1.587	243.5	1.611	243.3	1.635	243.2	1.658
05066+0152	HJ 2250	56.2	13.291	55.9	13.341	55.6	13.391	55.4	13.442	55.1	13.493
05588+7134	STF 793	278.2	3.566	280.4	3.434	282.7	3.306	285.3	3.185	288.0	3.071
06062+0629	STF 841	14.5	18.005	14.8	18.093	15.1	18.181	15.3	18.270	15.6	18.359
06345+0420	BAL 2672	11.1	9.727	10.8	9.794	10.4	9.862	10.1	9.930	9.8	9.998
11486+1417	BU 603	331.7	1.028	330.4	1.022	329.1	1.014	327.8	1.006	326.4	0.996
13198+4747	HU 644 AB	88.0	1.006	84.0	0.636	63.6	0.198	287.9	0.318	277.3	0.752
13443+6841	HJ 2685	267.9	21.513	268.1	21.593	268.3	21.672	268.5	21.753	268.6	21.833
14098+0822	A 1098	280.5	3.743	281.5	3.754	282.5	3.767	283.4	3.780	284.4	3.795
14203+4830	STF 1834	103.3	1.591	103.3	1.604	103.4	1.618	103.5	1.631	103.5	1.643
14489+0557	STF 1883	277.9	0.989	277.4	1.007	277.0	1.023	276.5	1.038	276.1	1.052
16264+5047	BEM 9021	52.1	18.433	52.4	18.460	52.7	18.488	53.0	18.516	53.3	18.544
17211+0127	STF 2150 AB	213.1	11.635	213.3	11.687	213.5	11.739	213.7	11.791	214.0	11.843
17344+2520	HJ 1300 AB	263.2	12.195	262.7	12.186	262.2	12.179	261.8	12.172	261.3	12.166
22016+4921	ES 831 AD	26.2	13.672	26.0	13.587	25.9	13.503	25.7	13.418	25.5	13.333

Table 6
Double Stars Not Found

WDS Designation	Discoverer Designation	Most Recent Published Observation: Date	θ (°)	ρ (″)	Reference	Published Magnitudes: Primary	Secondary	Notes
00049+3005	STT 548 AC	1861	64	28.6	Stt1878	8.2	…	1, 2
00089+3257	SEI 1	1894	231	10.6	Sei1908	10.5	11.0	3, 4
04380−1302	ENO 10 AC	1993	108	9.9	Lmp2001b	7.4	9.4	1
06249+3153	SEI 458	1894	170	28.8	Sei1908	11.4	12 0	1, 3
07344+2415	POU 2834	1902	21	7.1	Pou1933	10.3	11.3	1
08057+1251	BRT 3283	1896	165	3.1	Brt1935a	11.2	11.5	1, 3
09171−1617	J 2068	1942	195	4.	J__1942c	8.9	9.6	1
09267−1836	RSS 201	1976	343	8.1	Dom2002A	8.1	9.2	1
18589+1911	L 65	1910	68	8.7	L__1911	10.0	10.5	1
19496+3448	SEI 690	1894	296	15.8	Sei1908	12.2	11.0	3, 5
21331+3938	MLB 899 AB	1935	51	3.2	Mlb1936	11.0	11.4	6
21565+2613	CRB 17 AC	2011	57	5.2	Crb2012	9.3	…	1, 2

Notes.
(1) Companion not seen.
(2) Secondary magnitude unknown. Based on discovery method should be observable.
(3) Also a WFC1998 measure, extracted from the same Astrographic Catalog plate information used in the original reference.
(4) Neither component seen on POSS plate; may be flaws on AC Potsdam plate.
(5) Secondary not seen on POSS plate; may be flaw on AC Potsdam plate.
(6) Earlier observations in Mlb1934 and Mlb1935.

diverged from the most recent orbital solution (Seymour & Mason 2000); the period of the new solution is about 40 years longer, but may still be an underestimate.

WDS 14489+0557 (= STF 1883): This is another pair whose discoverer did not receive proper credit. Although observed by F.G.W. Struve in 1830 (Struve 1837), it was first observed by John Herschel a full two years earlier (Herschel 1831). The pair has now completed about 80% of a revolution, and as illustrated in Figure 1, the most recent data are beginning to diverge from the most recent published orbit.

2.2.2. *New Linear Elements*

All observed pairs with a 30° change in their position angle and/or a 30% change in separation since their first cataloged observation in the WDS were examined to see if their relative motion appeared linear. Such motion suggests that the pairs are either composed of physically unrelated stars or have very long orbital periods. Linear elements to 17 such doubles are given in Table 4, where Columns 1 and 2 give the WDS and discoverer designations and Columns 3–9 list the seven linear elements: x_0

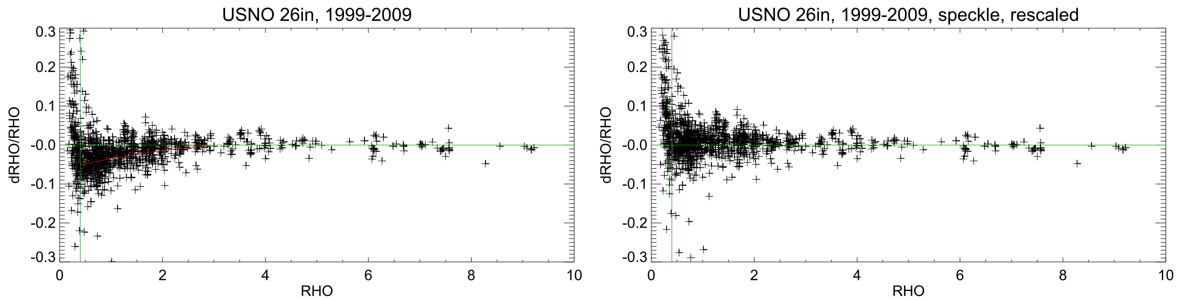

Figure 2. Left panel illustrates scale residuals to the second set of USNO 26 inch measures. The green horizontal line represents zero residual, while the green vertical line marks the 0."4 limit below which scatter is considered too large for the measures to be reliable. The red curve indicates the polynomial fit made to the residuals over the range 0."4–3". The right panel shows the residuals for these same data, after the polynomial fit has been applied.

Table 7
Recalibration Terms

Set No.	References	Date Range	a	b	ρ_0 ($''$)
1	WSI1997, WSI1999a, WSI1999b, WSI1999c, WSI2000a, WSI2000b, WSI2001a	1990.83–1999.721	−0.00695759	−0.0164030	2.0
2	WSI2000b, WSI2001b, WSI2002, WSI2004a, WSI2004b, WSI2006a, WSI2006b, WSI2007a, WSI2011 WSI2013b	1999.724–2009.89	−0.00347059	−0.0105567	3.0
3	WSI2007a, WSI2008, WSI2010 WSI2013b	2006.52–2008.99	−0.00937667	−0.00796677	3.0
4	WSI2011b, WSI2012, WSI2013, this paper	2010.00–2014.99	−0.000552786	−0.0153543	5.0

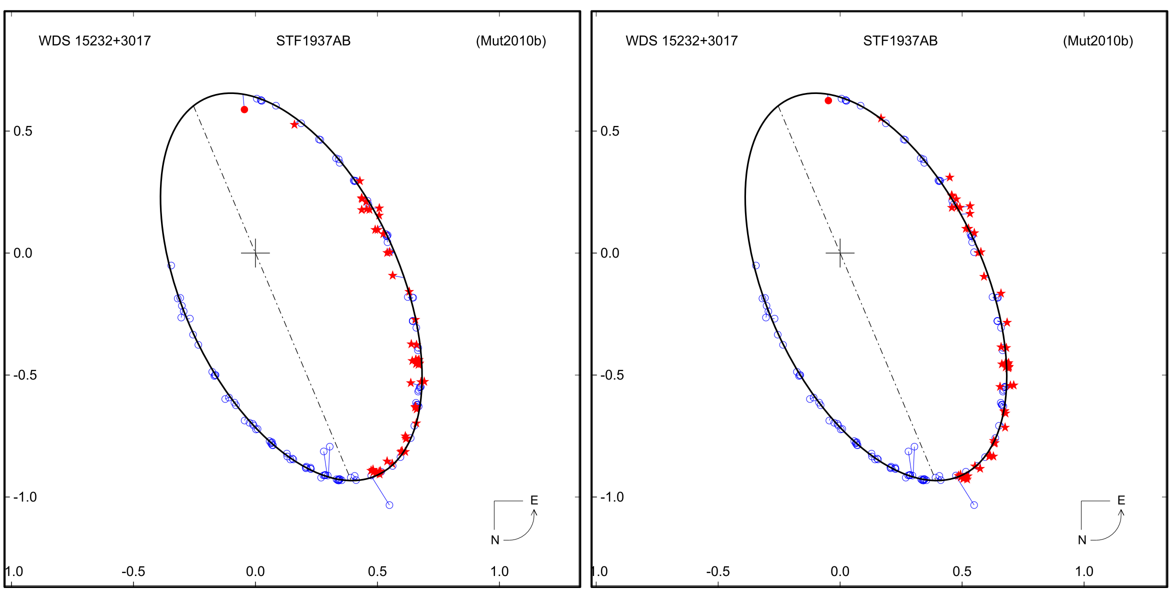

Figure 3. The orbit of WDS 15232+3017 = STF 1937 AB (Muterspaugh et al. 2010), showing USNO 26 inch data before (left) and after (right) scale adjustment. USNO data are shown as filled stars, other high-resolution (speckle and AO) data as open circles.

(zero point in x, in arcseconds), a_x (slope in x, in $''$ yr^{-1}), y_0 (zero point in y, in arcseconds), a_y (slope in y, in $''$ yr^{-1}), T_0 (time of closest apparent separation, in years), ρ_0 (closest apparent separation, in arcseconds), and θ_0 (position angle at T_0, in degrees). See Hartkopf & Mason (2011b) for a description of all terms.

Table 5 gives orbital and linear ephemerides for the pairs in Tables 3 and 4 over the years 2014 through 2022, in two-year increments. Columns 1 and 2 are the same identifiers as in Tables 3 and 4, while Columns 3 + 4, 5 + 6, etc., through 11 + 12 give predicted values of θ and ρ, respectively, for the years 2014.0, 2016.0, etc., through 2022.0.

2.3. Double Stars Not Found

Table 6 presents 12 systems which were observed but not detected. Possible reasons for nondetection include orbital or differential proper motion making the binary too close or too

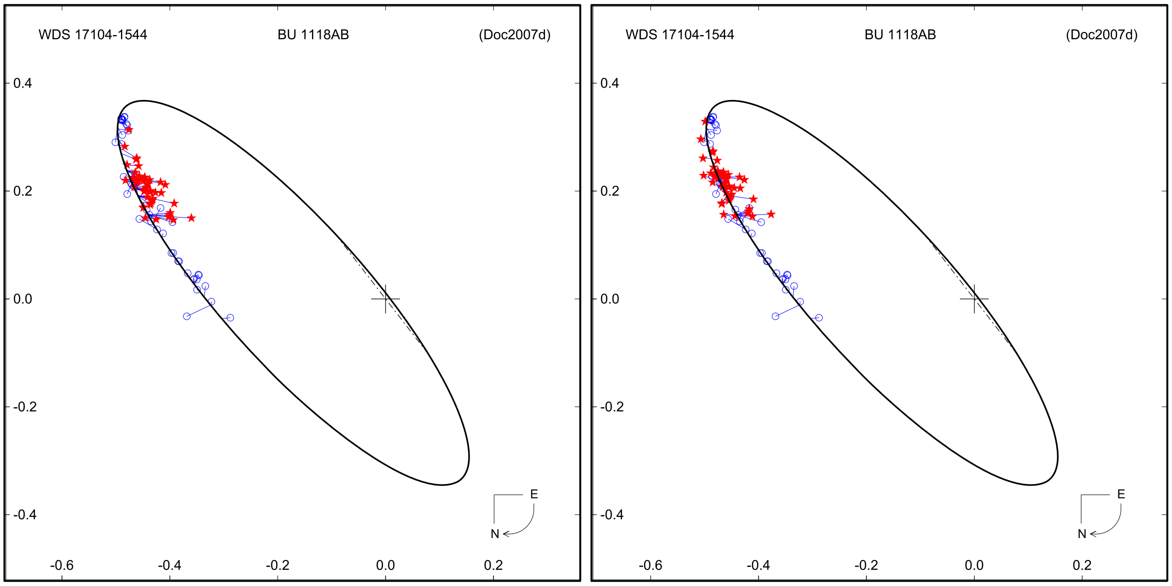

Figure 4. An orbit of WDS 17104−1544 = BU 1118 AB (based on a solution by Docobo & Ling 2007), showing USNO 26 inch data before (left) and after (right) scale adjustment. Symbols are as in Figure 3. Scatter in the 26 inch data appears more pronounced here, due in part to the close separation, but also to the southern declination of the pair.

wide to resolve at the epoch of observation, a larger than expected Δm, incorrect pointing of the telescope, and misprints and/or errors in the original reporting paper. It is hoped that reporting these missing pairs will encourage other double star astronomers to either provide corrections to the USNO observations or to verify the lack of detection. Notes to some of these pairs, highlighting some possible reasons for non-detection, are appended to the table. In all cases, the position angle, separation and magnitudes are those given by the discoverer of the pair.

3. RECALIBRATION OF OLDER USNO SPECKLE DATA

For some time an apparent systematic difference has been noticed between 26 inch speckle measures and other published data: ρ values for closer pairs tended to be too low, while those for wider pairs appeared to be in good agreement. This discrepancy was investigated using residuals to a large sample of well-determined orbits.

Orbits were selected from the *Sixth Orbit Catalog* (Hartkopf et al. 2001) if they met two criteria: (1) the elements characterized the motion of the binary well, and (2) the pair included at least one measure made using the USNO speckle camera. Orbits were then recalculated, if recent measures were showing some systematic runoff from the published solution, or if the orbit had been calculated including anything more than an inconsequential number of USNO measures (i.e., 2% of the total). USNO measures were given zero weight in any new orbit computations, of course. A total of 857 orbits remained in our sample following these recalculations; pairs included anywhere between 1 and 102 USNO measures.

Orbit residuals in θ and ρ ($d\theta$ and $d\rho/\rho$) were determined for all 6796 USNO speckle measures of these pairs, then subdivided according to the telescope used. Although the vast majority of measures were made using the USNO 0.66 m (26 inch refractor), data were also taken at several other telescopes, including the CTIO 4 m, KPNO 3.8 m, Mount Wilson 2.5 m, McDonald 2.1 m, and NOFS (USNO Flagstaff Station) 1.5 m. A few different cameras/detectors have been used during the 25-year USNO speckle program, so measures were further subdivided by detector.

Each set of residuals was then plotted against numerous terms—separation, position angle, date, magnitude, magnitude difference—and examined for any systematic trends. The only pairings indicating systematic trends were in scale versus separation for the various sets of 26 inch data (see Figure 2 for an example). No trends of any sort were seen in data obtained at other telescopes, even though detectors and reduction techniques were the same. We experimented with other background subtraction methods and conferred with other astrometry experts, but were unable to determine a cause for these trends, or why they only appeared in data obtained with the 26 inch refractor. In the end it was decided that an empirical correction to the scale for closer pairs was the best option.

Accordingly, weighted polynomial fits were determined for each data set. Residual plots for each detector were first examined to determine the range in separation to be fit. Residuals to the closest pairs (separations $<0\rlap{.}''4$, or about twice the Rayleigh resolution limit of a 0.66 m telescope in V-band) were too large to be useful, so were given zero weight. Table 7 lists each equipment setup, the papers published using that setup, the date range covered, and the polynomial terms. Here the polynomial is of the form:

$$d\rho = a * (\rho_0 - \rho)^2 + b * (\rho_0 - \rho)$$

and is applied over the range $0\rlap{.}''4 < \rho < \rho_0$. As an example, Figure 2 shows the fit made to the residuals from set 2, as well as the adjusted residuals.

Figures 3 and 4 give "before and after" plots of a couple orbits, made as a "sanity check" of our correction terms. For clarity, only high-resolution measures (those made using speckle, AO, or other interferometric techniques) are plotted against the orbit. USNO measures are shown as filled red stars, others as filled blue circles. Each "before and after" plot for a

given pair shows the same orbit, calculated without any of our 26 inch measures.

Nearly 16,000 26 inch speckle measures of close pairs (i.e., those closer than the upper separation limits given in Table 7) have been published since 1997. Of these, 529 are under 0."4, so have been "X-coded" (given zero weight) in the WDS; the remaining measures have been corrected using the above-described polynomial terms. Finally, many pairs observed early in the USNO speckle program were observed on numerous occasions (sometimes as often as ten times over a 2-week period), with each measure published individually. These multiple measures have been replaced in the WDS with mean values when appropriate; θ and ρ error columns indicate the weighted rms scatter for each mean value. In total, 15,691 old measures were replaced with 10,505 new rescaled or reweighted measures or means. All adjusted values have been flagged accordingly.

The continued instrument maintenance by the USNO instrument shop, Gary Wieder, Chris Kilian and Eric Ferguson, makes the operation of a telescope of this vintage a true delight. Thanks to Andrei Tokovinin for his design of our new "simple lens" camera. Thanks also to Ted Rafferty (USNO, retired) for his assistance with equipment upgrades and maintenance, and the foresight to initiate the secondary camera project.

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